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OBSERVATIONS OF SiO MASER SOURCES AT 43.122 GHz

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ABSTRACT

Eight new SiO maser sources were detected at 43.122 GHz in a search made in 1977 August with the Itapetinga radio telescope, from a search list of about 80 objects which included Mira variables, M supergiants, carbon stars, and S stars. One of the new sources is a symbiotic star, the first star of this type to present maser emission. Eighteen previously known SiO sources were reobserved, and the H_2O emission at 22.235 GHz of the SiO sources was observed at the same epoch, to provide a measurement of ratios of SiO to H_2O maser fluxes. The interesting implications of our results are discussed.

Subject headings: interstellar: molecules — masers — stars: late-type

I. INTRODUCTION

Silicon monoxide maser emission has reached in recent years an importance comparable to that of the OH and H_2O masers as a tool for investigation of the envelopes of late-type stars. Following the first detection of 86.243 GHz maser emission assigned to the ($v = 1, J = 2$–1) transition of SiO (Snyder and Buhl 1974), three other SiO transitions were also found to show maser emission in a number of sources: the ($v = 1, J = 1$–0) transition at 43.122 GHz (Snyder and Buhl 1975) and the ($v = 2, J = 1$–0) transition at 42.820 GHz (Buhl *et al.* 1974). Extensive searches for new SiO sources have been made at 86.243 GHz by Kaifu, Buhl, and Snyder (1975), at 43.122 GHz by Snyder and Buhl (1975), at 86.243 and 43.122 GHz by Blair and Dickinson (1977), and simultaneously at 43.122 and 42.820 GHz by Balister *et al.* (1977), yielding a total of 40 SiO sources, all associated with late-type stars, with the possible exception of Orion A. Most of these SiO sources were detected among known H_2O stars, although the detection of SiO emission in a few objects which do not show H_2O emission, like S-type stars, indicated that the class of SiO stars could be more extended; however, because of the variability of the sources, a better investigation of the relationship between SiO and H_2O emission required simultaneous observations of both molecular lines.

Following the installation of a new 42–48 GHz receiver at the Itapetinga radio telescope, we made a search for ($v = 1, J = 1$–0) SiO sources in 1977 August, during which eight new sources were detected. We also detected 18 previously known SiO sources, and we observed the 22.235 GHz H_2O line of most of the detected SiO sources with the same antenna and at the same epoch in order to obtain accurate measurements of the ratio of H_2O to SiO microwave fluxes. Some of the SiO sources showed interesting changes in their spectra since the previous detections; several implications of our observational results are discussed. After our observational period we learned of new searches by Spencer *et al.* (1977) and by Dickinson *et al.* (1978); none of the SiO detections reported in these two papers are coincident with the sources detected in the present work.

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II. OBSERVATIONS

The 43.122 GHz observations were made during 1977 August with the 13.7 m Itapetinga radio telescope, using a double-sideband mixer of about 1000 K system temperature and a 46-channel, 100 kHz resolution filter bank. An on-on beam-switching technique was used, with two linear polarization feed horns 9′ separated. Typical search runs consisted of 1 hour observations; for the weakest sources detected, several spectra taken on different days were averaged.

Antenna temperatures were corrected for antenna gain degradation with zenith angle, radome attenuation, and atmospheric attenuation $e^{\tau \sec z}$. The radome transmission at 43 GHz is about 0.66, this frequency being close to a minimum of transmission of the radome material; the τ values for atmospheric attenuation were typically about 0.3. The antenna gain degradation was found to be smaller than 30% between 20 and 80 degrees of elevation, with maximum aperture efficiency toward higher elevation angles, attaining about 50%, as determined from observations of planets and Virgo A (Kaufmann, Schaal, and Rafaelli 1978); the resulting factor to convert corrected antenna temperatures to flux units is 42 Jy for 1 K.

The H_2O line observations at 22.235 GHz of the SiO sources studied in this work were made at the beginning of 1977 September, less than 1 month after the SiO observations, which is a short delay compared with the periods of the stars studied. For the H_2O line observations we also used a double-sideband mixer receiver, with the same back end and the same observational technique as for SiO, the system temperature being about 1000 K. At 22 GHz a factor of

TABLE 1

NEW MASER SOURCES OF ^{28}SiO $v = 1$, $J = 1$–0 EMISSIONS AT 43.122 GHz

NAME	SPECTRAL TYPE	PERIOD (days)	PHASE IN OPTICAL CYCLE	SiO Integrated Flux (10^{-20} W m^{-2})	SiO LSR Velocity (km s^{-1})	H_2O Integrated Flux (10^{-20} W m^{-2})	H_2O LSR Velocity (km s^{-1})	DISTANCE (pc)	NOTES
R Aqr	M7e	387	0.53	5	−25.0	< 3	...	181*	Symbiotic star
R Cae	M6e	391	0.01	11	+1.5	< 3	...	440*	
R Car	M4e–M8e	309	0.51	38	+5.0, +10.0	< 3	+9.0[a]	144	Binary,[b] H_2O[a]
T Lep	M6e–M8e	368	0.06	13	+28.5	< 3	...	306*	
RW Sco	M5e	390	0.02	17	−70.5	12	−70.5	600*	OH[c]
R Tau	M5e–M7e	324	0.06	18	+9.5	< 3	+11.0	594	H_2O[d]
S Vir	M6e–M7e	378	0.51	13	+5.0	< 3	+14.0	477	H_2O[a]
IRC −30308	...	...	...	8	+1.5	< 3	−14.0	...	H_2O,[e] OH[f]

* The distances marked by an asterisk were estimated from the 4 μm magnitudes (see text).

REFERENCES.—[a] Lépine and Paes de Barros 1977; [b] Feast 1970; [c] Bowers and Kerr 1977; [d] Dickinson 1976; [e] Lépine, unpublished result; [f] Baudry, Le Squeren, and Brillet 1977.

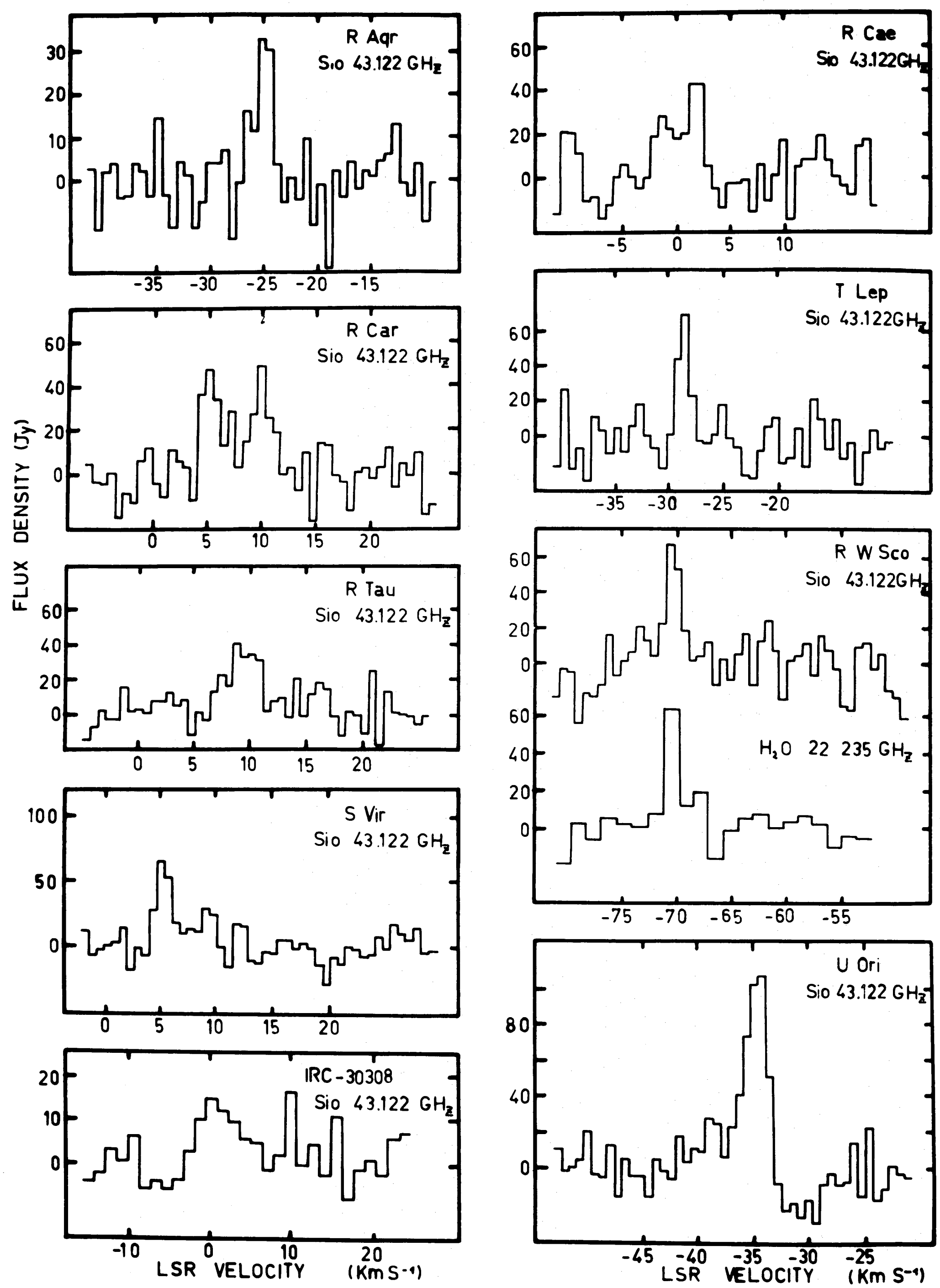

FIG. 1.—SiO $v = 1$, $J = 1$–0 spectra of R Aqr, R Cae, R Car, T Lep, U Ori, R Tau, RW Sco, S Vir, and IRC −30308 obtained in 1977 August. The H_2O 6_{16}–5_{23} spectrum of RW Sco is also shown. All the spectra shown in this figure are new detections, except U Ori.

39 Jy for 1 K was used to convert corrected antenna temperatures to flux units.

III. RESULTS

We detected eight new 43.122 GHz SiO sources from a search list of about 80 objects which included stellar H_2O or OH sources, Mira variables, carbon stars, S stars, and other bright infrared objects. The observed characteristics of SiO lines and H_2O lines, as well as the distances and the phases at the epoch of observation of the new SiO sources, are given in Table 1; their spectra are presented in Figure 1. The phases were calculated from the epochs of maximum and periods given in Kukarkin *et al.* (1969) or Lockwood and Wing (1971) or Lockwood (1972) when available. Most distances were taken from Lépine and Paes de Barros (1977); for the stars which were not included in their list, or which showed discrepancies between distances from V and I magnitudes in their paper, we estimated the distances (indicated by an asterisk in Tables 1 to 3) from the 4 μm magnitudes given in the AFCRL catalog (Walker and Price 1975), assuming for the Mira variables an absolute 4 μm magnitude independent of the period and equal to -8.1, which was determined from a sample of stars with known distances.

We also observed 18 known 43.122 GHz SiO sources in order to study their variability and to compare the SiO and H_2O line intensities. The observed characteristics of these sources are listed in Table 2, where the phases and the distances of the stars are as in Table 1. We present in Figures 1 to 3 the spectra of 13 of these sources which were selected because interesting changes have occurred since previous detection or in some cases because we have a better signal-to-noise ratio; the spectrum of one of the stars, CIT 3, had not yet been published.

The results of the H_2O observations at 22.235 GHz corresponding to detected SiO sources are included with the SiO results in Tables 1 and 2. With the exception of R Aqr, R Cae, T Lep, and RW Sco, all 26 SiO sources listed in these two tables were previously known H_2O sources. We detected, however, H_2O emission in only 11 of the 26 SiO sources studied here, including RW Sco, which is a new H_2O source. For the remaining stars we obtained an upper limit of about 20 Jy for the H_2O emission, or about 3×10^{-20} W m^{-2} integrated flux, considering a typical width of 2 km s^{-1}. Since the main purpose of the H_2O observations was to compare 43.122 GHz SiO and 22.235 GHz H_2O line fluxes measured at the same epoch, we also observed a number of known H_2O sources for which we obtained negative SiO results. The results of these observations are presented in Table 3: we detected H_2O emission from six known H_2O stars for which we obtained negative SiO results.

The list of negative results in the search for SiO emission is presented in Table 4; a 3 σ upper limit of about 60 Jy was obtained for these objects. The coordinates of the stars were taken from Neugebauer and Leighton (1969) or from Kukarkin *et al.* (1969), except as otherwise noted. The 32 km s^{-1} coverage filter battery was centered on the optical absorption-line velocities, or on the H_2O line velocities for the H_2O source.

IV. DISCUSSION

a) Comments on Individual Sources

Most of the new SiO sources detected are normal Mira variables, with observed characteristics comparable to the other stars of this class. Some sources, however, have interesting properties, deserving separate comments.

R Aquarii is a symbiotic star; our result is the first detection of a maser line in such objects. Negative results have been obtained for R Aqr in the OH lines (Wilson and Barrett 1972) and in the H_2O line (Dickinson 1976; Lépine and Paes de Barros 1977; this work), suggesting that the H_2O emission is inhibited by the close companion, since a normal Mira situated at less than 200 pc should show easily detectable H_2O emission (Lépine and Paes de Barros 1977). The detection of the SiO line indicates that the SiO maser is less affected by the presence of a companion star than the H_2O and OH masers, as is expected if the SiO emission comes from deeper and denser parts of the envelope. This effect had already been noted in the case of the binaries o Cet and R Hya (Lépine and Paes de Barros 1977) and is possibly present in R Car, as discussed below.

R Carinae was found by Lépine and Paes de Barros to be a weak H_2O emitter compared with normal Miras. We only recently learned that R Car has a companion (Feast 1970), which may explain the anomaly.

The absolute SiO line flux that we obtain for this star lies in the usual range for normal Miras, as discussed later in the text, indicating that the SiO emission is not perturbed by the companion.

IRC −30308 was detected at the H_2O line frequency in 1976 July, showing a feature at -14 km s^{-1} (unpublished result). It also showed OH emission, with several features in the range of -20 to 10 km s^{-1} (Baudry, Le Squeren, and Brillet 1977). Although the spectrum presented in Figure 1 looks noisy, the presence of SiO emission has been confirmed by observing with the filter bank displaced by 15 km s^{-1}. This object lies in a direction close to the cluster M6, but whether it is a member of the cluster is uncertain (Ney and Humphreys 1974). On the basis of photometric observations, Warner and Wing (1977) suggest that it is a high-luminosity supergiant similar to S Per and VX Sgr, and the wide velocity range of the OH emission is another argument in favor of the supergiant nature of this star. The observed magnitude of IRC −30308 would then imply that it is situated at a much larger distance than the cluster M6.

L_2 Puppis was previously known as a SiO and H_2O source (Balister *et al.* 1977; Lépine, Paes de Barros, and Gammon 1976). The SiO and H_2O spectra that we obtained (Fig. 2) show two features, which is an

TABLE 2

RESULTS OF OBSERVATIONS OF KNOWN SiO $v = 1$, $J = 1$–0 MASER SOURCES

		SiO		H_2O		PREVIOUS DETECTIONS		
NAME	PHASE IN OPTICAL CYCLE	Integrated Flux (10^{-20} W m^{-2})	LSR Velocity (km s^{-1})	Integrated Flux (10^{-20} W m^{-2})	LSR Velocity (km s^{-1})	SiO (43.122 GHz)	H_2O	DISTANCE (pc)
RR Aql.........	0.63	21	+29, −33.5	< 3	+28	a, b	c	316*
VY CMa.........	...	787	+2 → +37	405	−4, +14, +19, +36	a, b	d	1500
o Cet...........	0.88	49	+45, +47	9	+42, 48	a, b	e	77
CIT 3...........	...	47	+8	< 3	+22.5	b	e	346*
NML Cyg.......	...	53	−7	< 4	−19	a	f	...
R Dor..........	...	30	+4	54	+5.5	b	g	234
W Eri..........	0.02	11	−2	10	−1	b	e	580*
U Her..........	0.76	79	−12, −15	15	−17	a	f	321
R Hor..........	0.88	26	+31	< 3	+36	b	h	177
W Hya.........	0.00	198	+38	284	+38	a, b	f	100
R Leo..........	0.41	189	−4	< 3	−1	a, b	c	129
R LMi..........	0.43	105	−2, −5	< 3	...	j	...	324
U Ori..........	0.98	50	−35	4	−36.5	b	c, i	282
Ori A...........	...	400	−7, +16.5	...	−5 → +20	k	l	500
L_2 Pup.........	...	103	+25, +41	32	+30, +36	b	h	64
VX Sgr.........	...	407	+1 → +18	91	−6 → +13	a, b	f	1500
WX Ser.........	0.55	19	+8	< 4	+8	a	e	562*
IK Tau.........	...	50	+29 → +43	21	+20 → +50	a	c	...

* The distances marked by an asterisk were estimated from the 4 μm magnitudes (see text).

REFERENCES.—[a] Snyder and Buhl 1975; [b] Balister *et al.* 1977; [c] Dickinson, Bechis, and Barrett 1973; [d] Sullivan 1973; [e] Dickinson 1976; [f] Schwartz, Harvey, and Barrett 1974; [g] Lépine, Paes de Barros, and Gammon 1976; [h] Lépine and Paes de Barros 1977; [i] Wilson *et al.* 1972; [j] Spencer and Schwartz 1975; [k] Thaddeus *et al.* 1974; [l] Cheung *et al.* 1969.

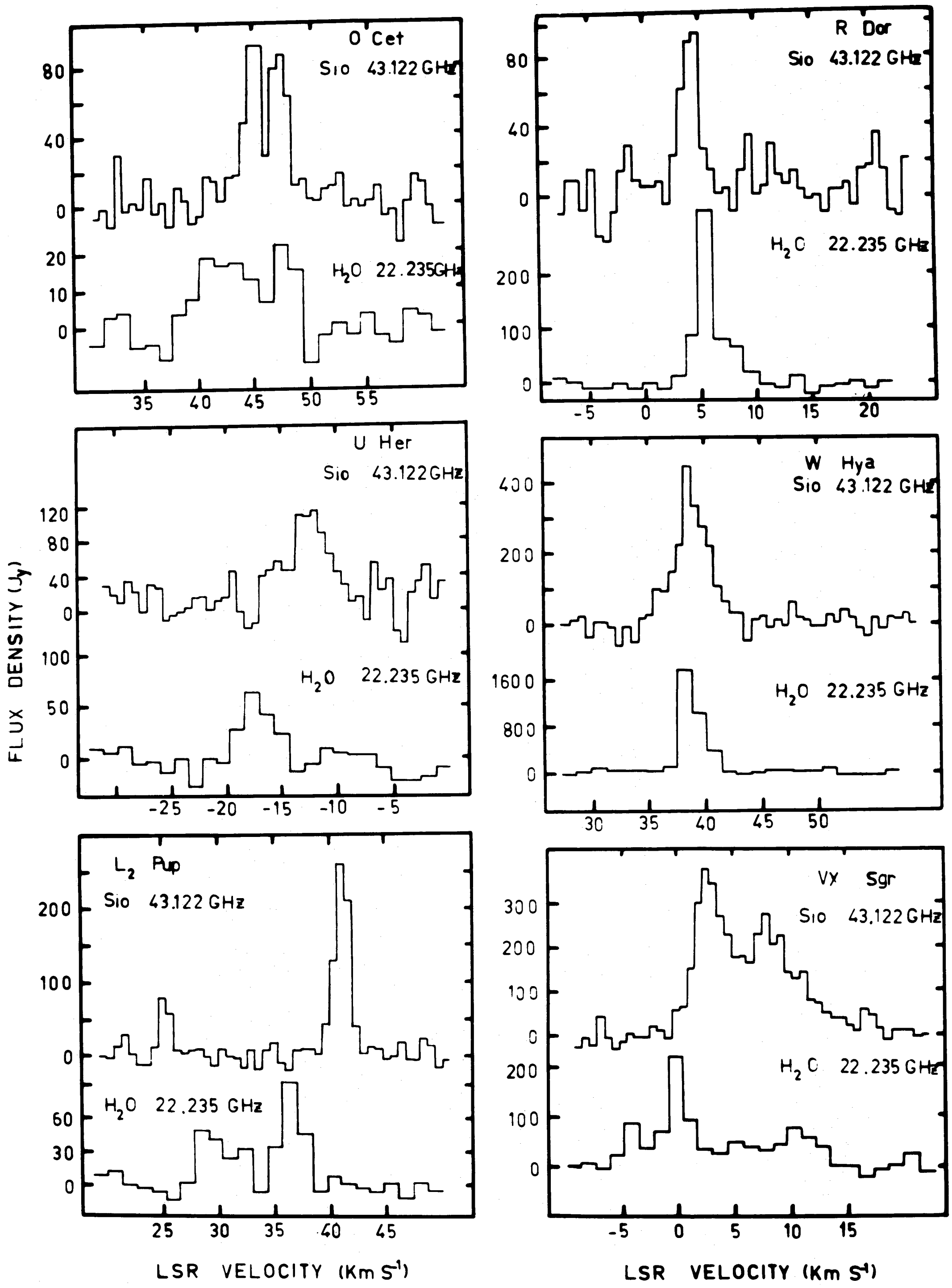

FIG. 2.—SiO $v = 1$, $J = 1\text{–}0$ and H_2O $6_{16}\text{–}5_{23}$ spectra of o Cet, R Dor, U Her, W Hya, L_2 Pup, and VX Sgr. The SiO spectra were obtained in 1977 August and the H_2O spectra at the end of 1977 August and beginning of 1977 September.

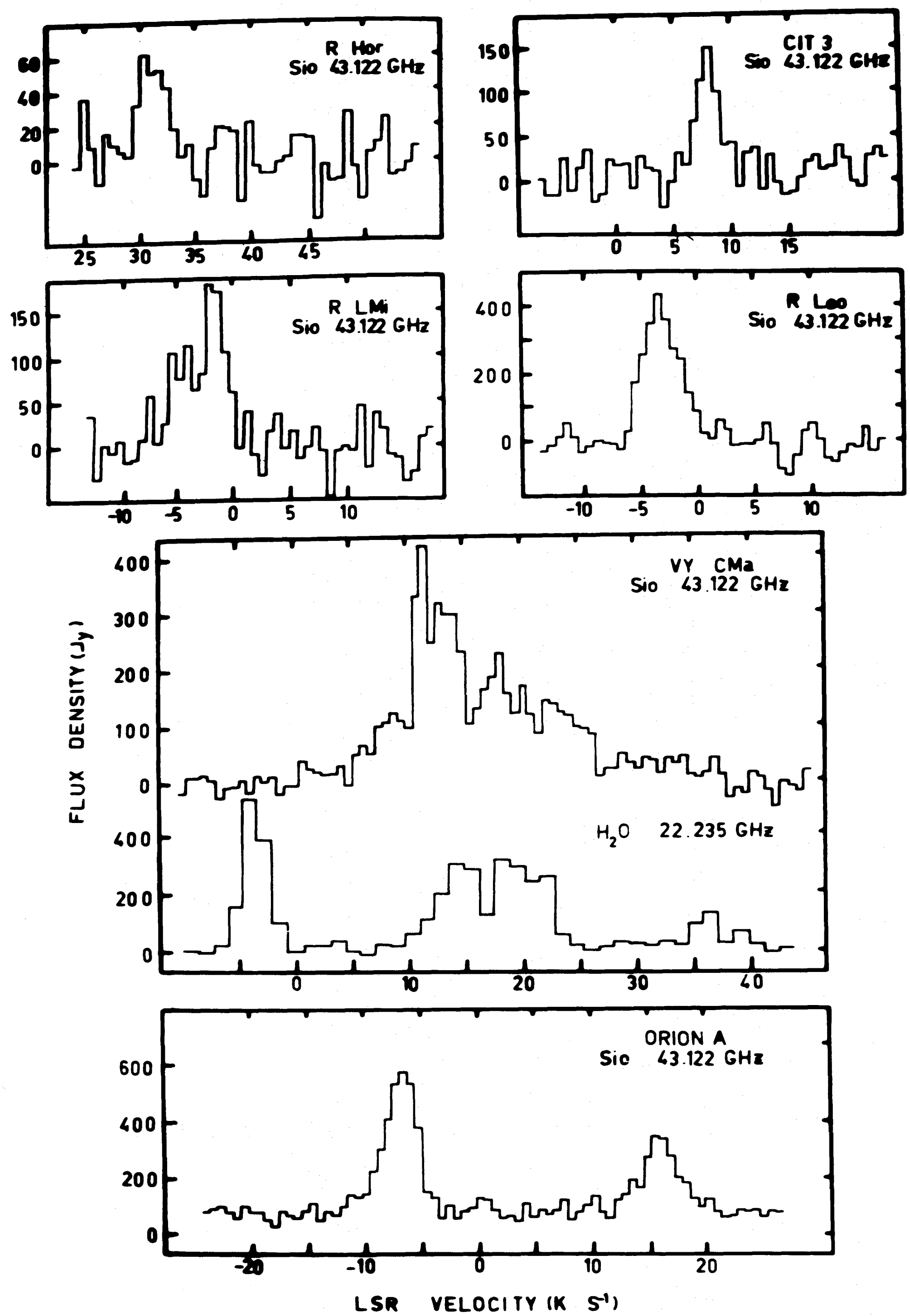

FIG. 3.—SiO $v = 1$, $J = 1$–0 spectra of R Hor, R Leo, R LMi, CIT 3, VY CMa, and Ori A, and H_2O 6_{12}–5_{23} spectrum of VY CMa, obtained in 1977 August.

TABLE 3

OBSERVATIONS OF H_2O SOURCES WITH NEGATIVE SiO RESULTS

Name	Phase in Optical Cycle	H_2O Integrated Line Flux (10^{-20} W m^{-2})	H_2O Line Velocity (km s^{-1})	Reference of Previous Detection: H_2O	Reference of Previous Detection: SiO	Distance (pc)
V Ant.........	...	6	−18	a	...	1227
R Aql.........	0.37	13	+47	b	c, d	252
S CrB.........	0.59	15	0, +5	b	c	384
R Crt..........	...	54	+3, +6, +13	e	...	294*
AH Sco........	...	67	−3	f	d	2600[g]
RS Vir.........	0.23	24	−14	f, h	...	630

NOTE.—The stars listed here showed no 43.122 GHz SiO emission stronger than 20 Jy in 1977 August, although the H_2O emission at 22.235 GHz was present.

* Distance estimated from the 4 μm magnitude.

REFERENCES.—[a] Dickinson 1976; [b] Schwartz, Harvey, and Barrett 1974; [c] Snyder and Buhl 1975; [d] Balister *et al.* 1977; [e] Dickinson, Bechis, and Barrett 1973; [f] Lépine, Paes de Barros, and Gammon 1976; [g] Baudry, Le Squeren, and Lépine 1977; [h] Baudry and Welch 1974.

interesting change since previous detections. The velocities of the features are symmetric with respect to the middle velocity of 33 km s^{-1}, which is close to the velocity of the star (35 km s^{-1}) given by the optical absorption lines of excited atomic levels (Wallerstein, private communication).

The separation of the two SiO peaks, of 12 km s^{-1}, is larger than the separation of the H_2O peaks, suggesting a spherically symmetric expanding envelope in which the regions closer to the star, where the SiO emission originates, would have higher expansion velocity than more distant regions, as in the model discussed by Lépine *et al.*

b) *Variability*

A relatively large number of strong SiO sources associated with standard OH–H_2O stars have been observed at 43 GHz in two previous works, by Snyder and Buhl (1975) and by Balister *et al.* (1977), allowing a crude discussion of long-term variability. In a sample of nine stars the ratios of our fluxes to the fluxes measured 3 years before by Snyder and Buhl vary between 0.1 and 3. This range is incidentally the same found by Balister *et al.*, who also compared their results with those of Snyder and Buhl. The SiO observations of Balister *et al.* and ours, which were made after little more than a 1 year interval, show remarkable consistency: in a sample of 14 stars, the ratios of our fluxes to those of the Australian group vary between 0.4 and 4, the differences being smaller than 50% for 10 sources. These results show first that there is good agreement between our calibration of the flux scale and those of the Kitt Peak and Parkes radio telescopes, and second that the amplitudes of variation of the SiO sources are relatively small. Although the variations of SiO emission of Mira variables are presumably periodic, like OH and H_2O emission, the comparison of our results with those of Balister *et al.* does not clearly show the periodicity, possibly because of cycle-to-cycle changes in amplitude. For instance, for R Leo we found about twice the flux measured by Balister *et al.*, although our measurement was made much nearer to the minimum of its optical cycle.

Changes in the relative intensity of spectral features occurred in several sources: the lower-velocity peaks of Orion A and VX Sgr are more intense in our spectra than the higher-velocity peaks, contrary to the observations of Balister *et al.*; new features appeared in the spectra of *o* Cet and L_2 Pup, while for R Dor we detected only one peak, and R Hor showed SiO emission at a different velocity. These variations, which are apparently erratic, seem to have typical time scales of the same order of the periods of the Miras. We looked for short-term variability in the sufficiently strong sources (with fluxes greater than about 200 Jy), obtaining for most of them many SiO spectra distributed along the observational period; we detected no clear short-term variation except for one star. In particular, we observed no variation of the relative intensities of the two main features which appear in the spectra of Orion A, VX Sgr, and VY CMa. The exception is W Hya, for which we observed a net increase of about a factor 2 from the beginning to the end of 1977 August. We also observed a steep increase of its H_2O flux, corresponding to the maximum of the optical cycle; complete variation curves for this star will be published later.

c) *Occurrence of* SiO *Emission and Relationship with* H_2O

Most of the known SiO stars are Mira variables; it is thus interesting to investigate the distribution of SiO absolute fluxes in this homogeneous class of stars, as was done by Lépine and Paes de Barros (1977) for the H_2O emission. The distribution of the absolute SiO photon rates of the 19 Miras that we observed (excluding the supergiants and the symbiotic star R Aqr), computed from the integrated fluxes and the distances given in Tables 1 and 2, is shown in Figure 4. Although the observations were made at arbitrary phases of the optical cycle and the fluxes are not

TABLE 4
NEGATIVE RESULTS

Name	Remarks
V Ant	M7e, OH,[a] H_2O[b]
X Aqr	S6e
RV Aqr	Ce
W Aql	S3.9e
T Ari	SRa, M6e–M8
RZ Ari	M6
RS Cnc	M6e
RT Cap	C5
CK Car	M supergiant[c]
EV Car	M supergiant[c]
IX Car	M supergiant[c]
T Cet	SRb, M5e
W Cet	S7.3e
α Cet	M2 III
R Cha	M6e–M7e
UX Cyg	M4e–M6e, OH,[d] H_2O[b]
U Del	Lb, M5 II–III
Br Del	M8e
Z Eri	SRb, M4 III
τ 4 Eri	M3
R For	Ce
R Gem	S3.9e–S6.9e
R Gru	M7e
S Gru	M8e
U Hor	M6e
U Hya	SRb, C7
V Hya	SRa, C6e
RU Hya	M6e, OH,[e] H_2O[b]
S Ind	M6e, OH[f]
W Leo	M6e, OH[f]
R Lep	C7e
S Lep	SRb, M6
σ Lib	M
Y Lup	M7e, OH[g]
V Lyr	M7e
T Mic	SRb, M6e
U Mic	M6e, OH,[g] H_2O[h]
V Mic	M6e, OH,[i] H_2O[h]
V Mon	M5e–M8e
RR Mon	S7.2e
δ Oph	M1
W Ori	SRb, C5
GP Ori	Se
S Pav	SRa, M7
RV Peg	M6e, OH[f]
SV Peg	SRa, M7, H_2O[b]
TW Peg	M supergiant, H_2O[b]
S Phe	SR, M6e
S Pic	M7e–M8e, OH[g]
TV Psc	SR, M3
TX Psc	C6
Z Pup	M4e–M9e, OH,[f] H_2O[b]
R Sge	RVb
R Sgr	M4e–M6e
SU Sgr	SRb, M6
RS Sco	M5e–M8e
RT Sco	M6e–M7e
BM Sco	K2.5 Ib[j]
R Scl	C6
S Scl	M3e–M8e, H_2O[h]
R Sct	RVa
R Ser	M6e–M8e, H_2O[h]
τ 4 Ser	M5
R Tri	M4e–M8e
Z Vel	M9e

REFERENCES.—[a] Dickinson and Chaisson 1973; [b] Dickinson 1976; [c] Humphreys *et al.* 1972; [d] Wilson and Barrett 1972; [e] Fillit *et al.* 1972; [f] Fillit *et al.* 1973; [g] Bowers and Kerr 1977; [h] Lépine and Paes de Barros 1977; [i] Caswell *et al.* 1971; [j] Ney and Humphreys 1974.

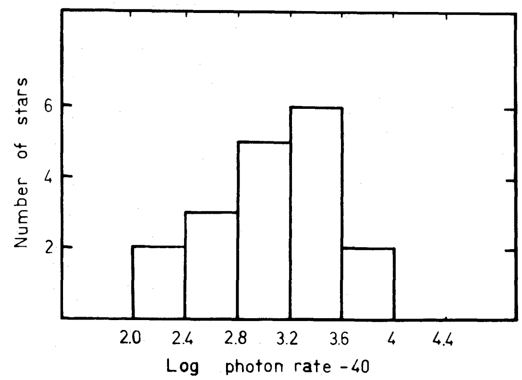

FIG. 4.—Histogram of SiO $v = 1, J = 1$–0 emission photon rates of the Mira variables observed in this work. The horizontal scale is logarithmic.

corrected for variability, the distribution is clearly peaked, with a dispersion smaller than a factor 100. Only detected SiO sources are included in this histogram; however, an examination of the Miras nearest to the Sun indicates that this distribution is representative of all the Miras. For instance, in the list of the regular long-period variables closer than 320 pc given by Lépine and Paes de Barros, 12 of 18 stars are already detected SiO sources, including the recent detection of RR Sco by Dickinson *et al.* (1978).

The same proportion of stars are already detected sources in the sample of all the Miras closer than 320 pc, including the Srb stars, the binaries like R Hya and o Cet, and the symbiotic Mira R Aqr. It seems then that the SiO emission is a normal property of the Miras, like the H_2O emission, the distance of the star being the strongest criterion for detection. This statement is in conflict with the correlation between SiO maser luminosities and spectral types found by Cahn (1977); we think, however, that his correlation must be reconsidered after the detection of SiO emission from Miras with spectral types as early as M4 and M5 at maximum, such as R Car and R Hor, which should not present SiO emission according to his paper.

The peak of the distribution of the SiO photon rates corresponds to about 2×10^{43} photons s^{-1}; this peak would be slightly shifted toward higher photon rates if the stars were observed at the maximum of their cycle. This photon rate is in close coincidence with the H_2O emission photon rate at maximum of about 4×10^{43} photons s^{-1} found by Lépine and Paes de Barros, a result which may seem surprising since the two molecules have such different level patterns and may also have different abundances. A possible explanation of this coincidence could be the existence of the same upper limit for the emission photon rates of the two molecules if both masers are pumped by near-infrared radiation and are saturated; this upper limit being the number of photons emitted per second by a Mira in a near-infrared pumping line, which is of the order of 10^{44} photons s^{-1} for a typical fractional line width $(\Delta\nu/\nu) = 10^{-5}$.

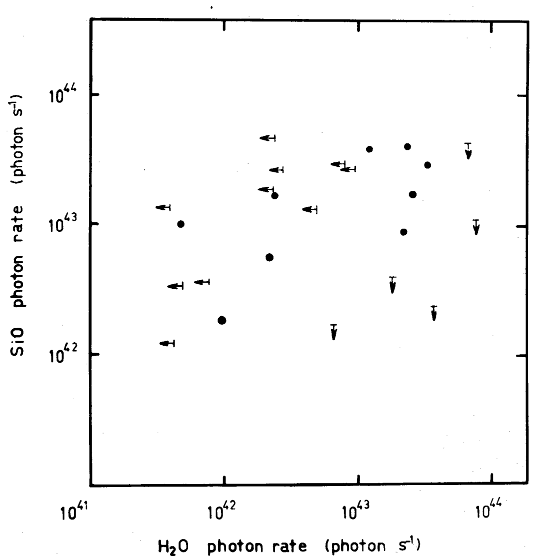

FIG. 5.—SiO $v = 1$, $J = 1–0$ emission photon rates versus H_2O $6_{16}–5_{23}$ emission photon rates of the Mira variables observed in this work. Both scales are logarithmic; the arrows indicate that only upper limits have been obtained.

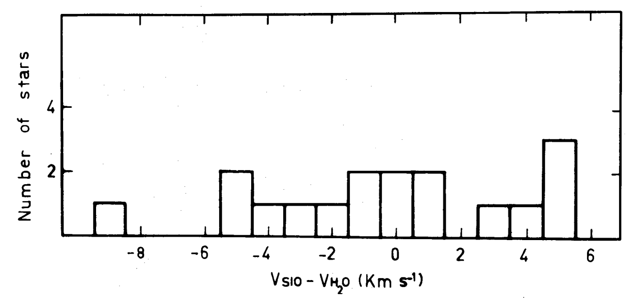

FIG. 6.—Histogram of the velocity differences V(SiO) − $V(H_2O)$ of the Mira variables observed in this work. The velocities from the references given in Tables 1 to 3 were used when we observed only one of the microwave lines. When two or more peaks appeared in the spectra, we considered the velocity of only the strongest one.

We found no correlation between the SiO and H_2O emission photon rates of the Miras, as shown in Figure 5. A correlation could be expected if the Miras had a wide range of infrared luminosities, or if a connection existed between the two masers, such as the pumping of the SiO maser by an H_2O line proposed by Geballe and Townes (1974). Additional evidence for the lack of relationship between the two masers is supplied by the recent detection of SiO emission in S-type stars, in which the H_2O molecules are depleted (Blair and Dickinson 1977). The strong association of SiO emission with OH–H_2O stars which was found in the first works on SiO can be simply explained by the fact that cool oxygen-rich envelopes and infrared radiation are conditions favorable to all three masers.

The ratio of emission photon rates SiO/H_2O does not show any clear dependence on the spectral type, on the period, or on the phase at the epoch of observation. The range of this ratio seems to be about the same for supergiants and for Miras; the only cases of clear predominance of SiO emission are the S-type stars and the double stars and symbiotic stars, as we already commented.

d) Relative Velocities of SiO *and* H_2O *Lines*

The histogram of the observed differences in velocities between the SiO lines and the H_2O lines is shown in Figure 6. No clear tendency for a systematic velocity difference can be seen in this histogram. This result may seem puzzling in the frame of the model of a spherically symmetric expanding envelope, since these lines are believed to be produced in different layers of the envelope, where the gas has not yet reached the terminal velocity, which would be represented by the OH line velocities. Only in a few cases, such as L_2 Pup and *o* Cet, do two SiO and two H_2O peaks appear in the spectra which could be attributed to the front and back halves of the envelope. A possible explanation could be that in most stars we are observing emission from maser amplification paths which are tangential to the layers in which the H_2O or SiO level populations are inverted, so that the gas in radial expansion presents no systematic velocity component along the line of sight. Indeed, in the regions close to the star where the gas is accelerated radially, the smallest velocity gradients, which are required for maser amplification, are found in tangential directions. If our hypothesis is correct the brightness distribution of the H_2O and SiO masers should present a maximum in the form of a ring around the star, which could be observed in VLBI experiments in the near future.

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